

DRAFT

VERSION 1

**STATEMENT OF WORK FOR
CONSTELLATION-X
SPECTROSCOPY X-RAY TELESCOPE (SXT)
FLIGHT MIRROR ASSEMBLY (FMA)
SYSTEM STUDY**

November 5, 2003

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1 INTRODUCTION

This statement of work describes the tasks comprising the systems design study for the Constellation-X Flight Mirror Array (FMA). Constellation-X is NASA's next flagship X-ray observatory, with an objective to perform high-resolution spectroscopy of the faintest sources detected by the Chandra X-ray Observatory. The FMA is the primary X-ray mirror system of Constellation-X. Each FMA (of four identical units) has the following major elements: thermal pre- and post-collimators, the Spectroscopy X-ray Telescope (SXT) mirror, the Reflection Grating Spectrometer (RGS) Grating Array (RGA), a rear cover door, and supporting structure. The heart of the FMA is the SXT mirror. This grazing incidence mirror combines high throughput and low areal density to provide a large effective area and moderate angular resolution. It incorporates a modular, segmented design to facilitate mass production and alignment, and relatively easily handling of components.

The outcome of the FMA study shall be a conceptual design of an FMA system in which the angular resolution and effective area requirements are met with adequate design margin and without violation of mass, envelope or other constraints. The requirements and constraints to be used for this study are tabulated in the *FMA Requirements Document*. It is desirable that the conceptual design provides an angular resolution that approaches the mission goal.

The contractor performing the FMA study is expected to base its work on the substantial technology development already performed by the NASA-led SXT FMA technology development team. A summary of this work is embodied in the *FMA Reference Package*. Reflector properties to be used for this study are provided in the *FMA Requirements Document*.

The several related tasks in this SOW lead the contractor from the Reference Concept to their own study design, which shall meet the requirements and constraints provided by NASA. The contractor shall perform risk assessments of the Reference Concept and study designs, define a prototype consistent with the study design, and produce fabrication, integration and test flows. The tasks to be performed are described in section 3; the study deliverables and schedule are summarized in section 4.

Two grating technologies are currently under consideration for the RGS Grating Array: in-plane and off-plane. The final grating form will be determined as a result of a competitive instrument Announcement of Opportunity (AO). An in-plane grating configuration has been assumed for this study and specific accommodation requirements are specified in section 6 of the *FMA Requirements Documents*. The results of this study will help define RGA to FMA interface requirements that will eventually be incorporated in the instrument AO.

Work under this SOW does not include development of any demonstration hardware. Neither does it include the study or development of processes by which the individual grazing incidence reflectors are made except to the extent that these processes affect the FMA manufacturing time and facilities requirements. Similarly, this study does not consider the manufacture of the mandrels needed for reflector fabrication. Section 8 of the *FMA Requirements Document* provides reflector fabrication process times, and representative mandrel delivery schedule to be used for schedule and facility planning

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

The following documents, to the extent specified herein, are applicable to the contents of the document as well as basic information used in its generation. These documents are subject to periodic revision, the user, therefore, should refer to the latest available version. In the event of a conflict between documents referenced herein and the requirements of this document, the requirements of this document shall take precedence.

<u>Document Number</u>	<u>Document Title</u>
<i>TBD</i>	FMA Requirements Document
<i>TBD</i>	FMA Reference Package

2.2 Reference Documents

TBD

3 TASKS TO BE PERFORMED

3.1 FMA Reference Concept Assessment

The contractor shall review and assess the FMA Reference Concept as presented in the *FMA Reference Package*. The contractor shall:

- Identify the technical and programmatic risks associated with the Reference Concept, and provide a preliminary plan for reduction or elimination of these in the Contractor's Study Design.
- Define areas in which margin exists for meeting the requirements and where it does not.
- Present an approach for removing inconsistencies and filling in missing aspects of the Reference Concept
- Identify those aspects of the Reference Concept where departure from the baseline design is anticipated for the Contractor's Study Design (within constraints defined in the FMA Requirements Document).

The intent of this task is to enable the contractor to develop and demonstrate familiarity with FMA Reference Concept before initiating a detailed design study. The Contractor will present the results of this task at the study kickoff meeting.

3.2 Develop Contractor's Study Design of the FMA

Drawing on the insight obtained from the previous task, the Contractor shall develop a "Study Design" for the FMA that meets the requirements of the *FMA Requirements Document*. The contractor shall provide enough detail to clearly show the approach taken and to support the contractor's assessments, error budgets, and plans. This may require more detailed design in some areas than in other areas and any resultant imbalance in the total package is acceptable. The term "Study Design" is used in this SOW to describe such a design package.

The desired final result of this task and its sub-tasks is a reasonably detailed definition of the Contractor's Study Design. This design package must include an in-depth assessment of the strengths and weaknesses of the contractor's specific implementation. Additional end items are defined as appropriate in the subtasks.

This task is organized into several sub-tasks. The total study effort is expected to be a highly iterative and closely coordinated process where the results from work in one task area may lead to changes elsewhere. In particular, the error budget process, manufacturing flow, assembly and alignment, and verification and calibration considerations must be considered in all relevant phases of the design activity. Preliminary Constellation-X planning has already shown that manufacturing flow coupled with schedule objectives are significant design drivers and the contractor must not overlook these factors when doing various design trades.

The Contractor shall develop the Study Design mindful of both the required and the goal angular resolution performance. Where an irresolvable conflict arises, the required performance governs. However, design decisions wherever possible should not preclude performance better than the requirement. Furthermore, design approaches having better angular resolution than the requirement, but poorer than the goal are, nonetheless, of interest to the Constellation-X Project provided all other factors taken together represent a net improvement.

3.2.1 Systems Engineering for the Study Design

3.2.1.1 Performance Budgets

The Contractor shall develop and maintain end-to-end angular resolution and effective area budgets for the Study Design. These budgets and updates thereto will be a key indicator of the Contractor's understanding of the performance of the designs being developed and analyzed. The Contractor is expected to use these budgets as an on-going design trade tool. Furthermore, as the Study Design matures and is modified, the performance budgets must also be modified to reflect the current design. Periodic updates will demonstrate the degree to which these are being done.

The Contractor's performance budgets shall account for all of the significant terms arising out of the FMA design and the sensitivity of that design to both design and environmental variables. A separate subsection of the budgets shall be established relating the reflective grating accommodation. The *FMA Reference Package* shows representative budget formats. The contractor may use any budget format that provides visibility into the main contributors to the FMA performance.

The Contractor shall prepare and maintain two angular resolution error budgets – one for the requirement and one for the goal. The *FMA Requirements Document* defines the values of reflector stand-alone optical performance to be used for this study. In this document, different reflector performance has been defined for the requirements budget and for the goal budget.

3.2.1.2 Requirements Flow Down

The Contractor shall derive and define “flow down” requirements for the FMA subsystems. These shall be derived from the FMA Requirements Document and consistent with the Contractor's Study Design and Performance Budgets.

The *FMA Reference Package* provides sample flow down requirements that are based on the FMA Reference Concept and associated performance budgets. It is anticipated that many of the Contractor's flow down requirements may be different from those of the Reference Concept. The Contractor shall provide rationale for the flow down requirements.

3.2.2 Optical Design

The contractor shall define the optical design of the FMA Study Design under the limitations defined by the *FMA Requirements Document*. Parameters to be defined shall include the number of shells (reflector diameters), the spacing between shells (reflectors), the reflector lengths (within the constraints defined in the *FMA Requirements Document*), the spacing between Primary (P) and Secondary (S) reflectors, etc .

3.2.3 FMA Structure Design

The Contractor shall develop an overall structure design as described in the following sub-tasks. This SOW assumes that the Study Design will use some sort of modular approach. It, however, makes no assumptions as to how such an approach is implemented.

3.2.3.1 Reflector Alignment, Support and Module Housing Design

The Contractor shall define how the individual reflectors are supported and adjusted within their support housing, how that adjusted alignment is maintained and the design of the housing in which it is supported.

The reflector housing is analogous to the mirror sub-module structure of the FMA Reference Concept. Separate sub-modules for the Primary (P) and Secondary (S) sections as incorporated into Reference Concept, may be used by the Contractor, but are not required. (The Contractor needs to consider whether

and how the S reflectors are adjusted to the previously adjusted P mirrors.) Module housing design must explicitly consider alignment determination and stability, load paths, possible distortions, thermal characteristics, area throughput obscurations, performance budget contributions, manufacturability and assembly.

The design is expected to be significantly affected by the processes and procedures for reflector assembly and alignment into their housings. The Contractor shall identify, evaluate, and document an approach to reflector assembly into their structural housing. This shall include, but not necessarily be limited to defining the process by which individual reflectors are installed into their housing, how they are adjusted and aligned, how that alignment is maintained (bonding, clamps, etc.), and how the alignment of the reflectors is transferred to the housing for subsequent alignment measurements and adjustments thereof.

The Contractor's design shall accommodate a precision stable support suitable for stand-alone alignment and optical and x-ray testing of a single module assembled with its reflector complement (both primary and secondary reflectors).

The Contractor should realize that mandrel availability (and therefore reflector availability, by diameter) will significantly affect the FMA assembly. The Contractor must state the order in which mandrels are to be delivered to support the Contractor's assembly scheme and schedule. Mandrel availability constraints are defined in the *FMA Requirements Document*.

The Contractor shall, to the greatest degree possible, devise procedures and designs such that completed modules of a given type can be directly interchanged or at worst, be interchanged with small adjustments in position of the total module assembly, e.g. with reference to alignment optics on the module housing.

Reflector alignment at GSFC and SAO is currently accomplished using a Centroid Detector Assembly (CDA) system and methodology derived from the Chandra program. The Contractor should become familiar with this system, but is not required to use it. Information regarding the CDA is contained in the *FMA Reference Package*.

3.2.3.2 RGS Grating Array (RGA) Accommodation

The Contractor shall define a Grating Integrating Structure (GIS) for mounting RGA grating modules within the FMA. For purposes of this study, the Contractor shall assume that the gratings are delivered to the FMA contractor packaged in the form of grating modules. Properties to be used for the grating modules and requirements for their accommodation (including number, placement, alignment tolerances, etc.) are specified in the *FMA Requirements Document*.

The Contractor shall assess options for the GIS design including, for example, the relative merits of a single separable monolithic structure, designs with multiple assemblies (e.g. a single grating assemble per mirror module), or a design that is more integral with the mirror structure. Study areas should include ease or difficulty of assembly and alignment, and x-ray test and calibration considerations.

The RGA will ultimately be obtained through an Announcement of Opportunity, which will be separate from the competitive solicitation for the FMA provider. Emphasis under this study is on accommodation of the grating modules.

3.2.3.3 Mirror and Overall FMA Structure Design

The contractor shall define the mirror structure and the overall FMA structure. The mirror structure provides support and alignment for all mirror modules. The contractor may consider use of an intermediate

structure suitable for holding several mirror modules for X-ray test and for the final build-up of the FMA. However, inclusion of such intermediate structure in the Contractor's Study Design is not required.

The task includes definition of all interface mounting points between all elements of the FMA including mirror, collimators, the GIS, and the internal cover, as well as interfaces to the Observatory. The FMA structure shall meet all structural load and temporal and thermal stability requirements. The design shall provide kinematic mounting (or equivalent) of the loaded housing to the Observatory.

As part of this task, the Contractor shall develop a top level FMA assembly and alignment procedure and provide in the design for all permanently attached alignment reference optics.

3.2.4 Thermal Control

The Contractor shall define an FMA thermal control system including pre and post collimators and heaters and heat pipes as needed. The objective is to maintain the required temperature and temperature gradient control while minimizing thermal control power, mass, and mirror assembly obscuration. The thermal control system need not be optimized, but the Contractor must develop and document sufficient detail to show that the thermal control design has a high probability of meeting the requirements and that the expected temperatures and gradients are consistent with the Contractor's error budgets. Thermal control assumptions to be used in the study are given in "FMA Study Reference Package".

3.2.5 Manufacturing, Integration, Test and Calibration

Using the Contractor's Study Design, the Contractor shall develop a preliminary concept for manufacturing, subsystem assembly/alignment and test, and integration, alignment, and verification testing for the full up FMA's. The Contractor shall develop a preliminary flow plan for the FMA showing the general flow of the manufacturing, assembly, and test of the modules and intermediate assemblies that taken together make up the FMA. Critical points in terms of both technical and program risk shall be identified along with parallel lines for various operations where such parallel operations are contemplated. This task includes everything up to delivery of the FMA for integration into the telescope. The Contractor is reminded that four FMAs are to be produced and that they are, under the current plan, integrated with the telescopes and launched two at a time. The flow shall show activities and phasing for all four FMAs.

This plan should not be elaborate, but must include an overall flow diagram with subordinate diagrams as needed. Sufficient narrative must be provided so that all steps in the flow are clear to a knowledgeable reader. A time estimate for the major activities is required.

3.3 Reflector Parameter Trade

The Contractor shall perform trades to determine the advantages and other impacts to varying the allowed parameters of the reflectors on the overall performance of the FMA. Such parameters to be studied include increased reflector length, etc. The results of this trade and/or reflectors that do not meet the constraints of the *FMA Requirements Document* shall NOT be directly incorporated into the Contractor's Study Design.

3.4 Prototype Unit Definition

The Contractor shall identify a prototype configuration which, when built and tested, is sufficient to verify the important aspects of the total FMA design (assuming some verification will be done by analysis). It is desirable that a complete prototype FMA not be required to verify the FMA design. Based on the Contractor's Study Design, the Contractor shall define a prototype unit that, together with straightforward analysis, is sufficient to demonstrate the adequacy of the overall design in the context of the relevant requirements of the *FMA Requirements Document*. The Contractor shall define the overall prototype unit,

demonstrate by analogy and analysis that it is sufficient to verify the design, and define testing, alignment, and alignment verification to be performed on the prototype unit. The task does not, of itself, require design of a prototype unit – it requires a concept for the prototype whatever its form and a cogent argument that the resultant prototype is sufficient to verify the critical elements of the overall FMA design.

3.5 Assessment of FMA Requirements

Based on experience in carrying out the other tasks in this SOW, the Contractor shall prepare a thorough, candid assessment of the FMA requirements as stated in the *FMA Requirements Document*. Particular emphasis should be placed on areas that created problems for the Contractor, or were unclear, or had more than one interpretation. The Contractor is invited to suggest alternate wording or definition of the requirements in question. The intent of this subtask is to provide explicit feedback to the Project regarding improvements to the FMA Requirements Document that may be needed.

3.6 Programmatic Summary

While a complete program plan is beyond the scope of the study, the Contractor shall develop material and provide discussion in accordance with the following tasks. The objective of the task is to provide the Contractor's preliminary assessments at the end of the study and not develop detailed or definitive information.

3.6.1 Schedule and Cost Estimates

The Contractor shall develop schedules and Rough Order of Magnitude (ROM) cost estimates to build and test four FMA's based on the Contractor's Study Design. Design, build, and test of the prototype shall be included as well as time and cost of activating lines, tooling design and fabrication. The schedules must reflect mandrel production and reflector fabrication durations. (See section 8 of the *FMA Requirements Document for related schedule assumptions to be used*.) For purposes of this study, the cost of reflectors and mandrels shall be excluded from the FMA cost estimates except for costs associated with their use by the FMA Contractor or subcontractors.

3.6.2 Risk Assessment

The Contractor shall identify and document the main technical and program risks associated with the Contractor's Study Design. This risk assessment shall include all phases of the program up to delivery of the FMAs.

3.6.3 Facilities and Special Equipment Identification

The Contractor shall identify and support the need for both special equipment and facilities needed to develop flight FMAs using the Contractor's Study Design.

3.6.4 Technology Transfer

As a matter of policy, the Constellation-X Project intends to transfer all useful FMA technology it has developed to industry, including technology related to reflector fabrication. To that end, the Contractor shall identify areas where technology transfer is either required or useful and suggest means and timeframe for technology transfer.

3.6.5 Assumptions

It is anticipated that in performing the total study, the Contractor will have to make interpretations of reference information as well as assumptions about specific issues. To make the output of the Contractor's

study as useful as possible, the Contractor shall document all interpretations and assumptions that have been made by the Contractor team wherever such interpretations and assumptions, if not generally correct, may have a significant effect on the validity of the Contractor's study product.

3.7 Reviews and Meetings

The Constellation-X Project desires effective and continuous bilateral communication with the Contractor. Reviews and meetings between the Contractor (Contractor team) and Constellation-X Project personnel shall be as defined in the Deliverables. Specifically, an initial Kick-Off meeting is required together with intermediate reviews and a Final Review before submission of the Final Report. In addition to these required interactions, the Contractor is encouraged to communicate informally at any point in the effort where the Contractor feels such interaction would be helpful in any way. The Constellation-X Project will support such requests for additional interaction as effectively as possible within personnel availability and funding limitations.

3.8 Final Report

The Contractor shall prepare a final report that documents all of the work carried out under this SOW, including but not limited to conclusions; performance budgets, predictions and margins; study design descriptions; plans; schedules; recommendations; and trades. If the design is not entirely responsive to the *FMA Requirements Document*, the Contractor shall so note in the Final Report.

The full Final Report shall be in Microsoft Word or PDF and submitted in draft form prior to the Final Review. A summary of the Final Report shall be provided in PowerPoint format and presented at the Final Review. If needed, the report shall be re-edited by the Contractor to reflect the results of that review. All supporting analyses, models, drawings, and internal design memos shall be provided in a mutually acceptable format. Preferred electronic format is CD-ROM.

4 DELIVERABLES AND SCHEDULE

The Contractor shall deliver the items specified in Table 3-1 in accordance with the schedule contained therein. Unless otherwise specified, reports are to be informal and can be in any format convenient to the Contractor. Electronic submissions of all documents are required. Use of MS Office (Word, PowerPoint, and Excel) is preferred, but not required.

Deliverable Item	Schedule	Remarks
Kick-off Meeting	Contract Start Date (CSD) + 3 weeks Data package: 2 hard copies 1 electronic copy	Data package required TBD days before review
Design Concept Review	CSD + 8 weeks Data package: 2 hard copies 1 electronic copy	Data package required TBD days before review
Mid-Study Review	CSD + 16 weeks Data package 2 hard copies 1 electronic copy	Data package required TBD days before review
Draft Final Report	CSD + 22 weeks Draft Final Report 2 hard copies 1 electronic copy	Draft final report due 2 weeks before final review
Final Review	CSD + 24 weeks Presentation Package: 2 hard copies 1 electronic copy	Presentation package required TBD days before review
Error Budget Updates	Monthly starting with kick-off meeting	Contractor's format with electronic copy.
Final Report	CSD + 26 weeks	TBD